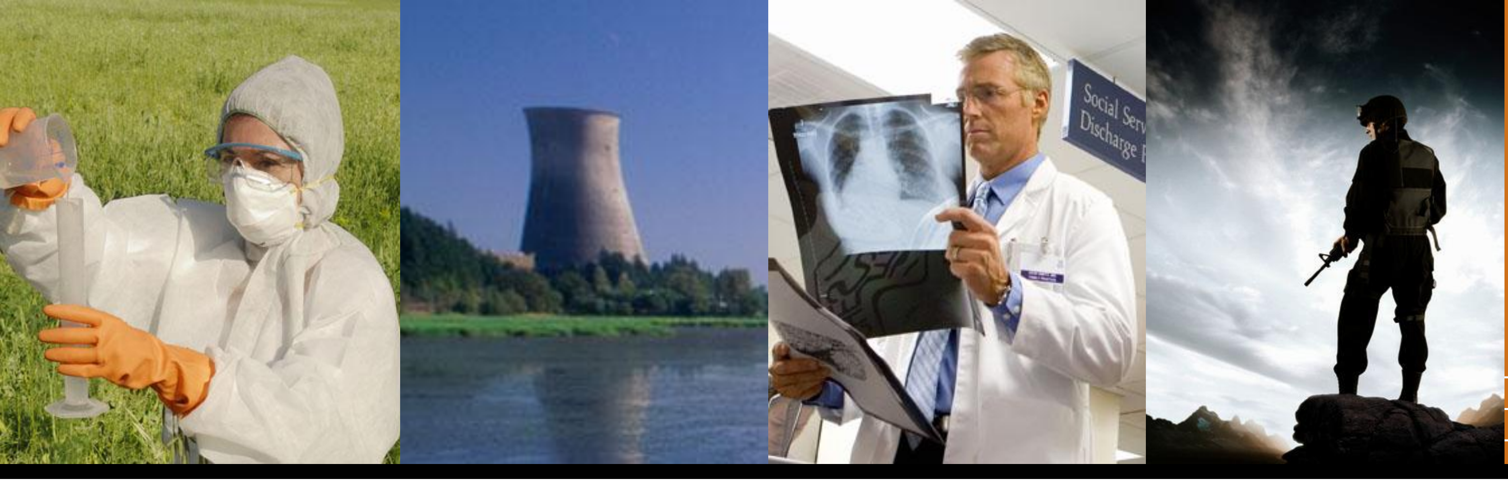

Digital I&C: Safety, Security and Availability
IAEA-CN-194-098

Third International Conference on Nuclear Power Plant Life Management (PLiM)
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MIRION TECHNOLOGIES Radiation Monitoring Systems Division

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1. Why digital signal processing for safety related applications

- Obsolescence of analogue components (Semiconductors, integrated circuits)
  - Reduction of component variety
  - Problem of spares

- No limitation for signal processing algorithms: precision and “flexibility”
  - Calculation of logarithmic scales
  - Combination of pulse signal and Campbell signal for the wide range “overlapping”
  - Calculation & precision of alarm thresholds (gradually shifting thresholds)
  - Multiplication , e.g. flow rate
  - Calibration, flexible parameters

2. Advantages of digital signal processing

- High degree of self monitoring for HW & SW
  - low risk of hidden failures
- Simplified periodical testing, extension of test interval
  - algorithms fixed in EPROM (and continuously monitored)
  - precision and response time determined (mainly) by software (= EPROM)
  - easy check of parameters
  - remotely activated test generators for input signals
  - numerical simulation of output signals

3. Mastering the risks of software

A software failure could become a common cause failure!

- Engineering-like development of software (state of the art!)
  - Carefully planning, design, simulation, coding
  - Aim -> zero-failure software
- Limitation to essential functions
  - KISS (Keep it simple, …)
- Continuous quality assurance & real safety culture
  - The SW engineer is aware of the safety critical environment of application (i.e. nuclear)
- Verification & validation
  - Type test certified by independent expert (TÜV)
- Operational experience (see proTK^{TM} / TK 250 features)

4. Mastering the risks of hardware

- Main risk: obsolescence of components (“computer products”)
- How to deal with this risk?
  - Use of well established components; no requirements for “best performing” in terms of speed, memory size, etc (= usually latest on market).
  - Re-design of fully compatible new boards with new components
  - E.g. proTK^{TM}
    - □ on market for more than 20 years
    - □ some boards are of 2nd generation, but:
      - ○ Fully exchangeable/compatible
      - ○ Re-qualification including test of compatibility

5. IT (Cyber) Security

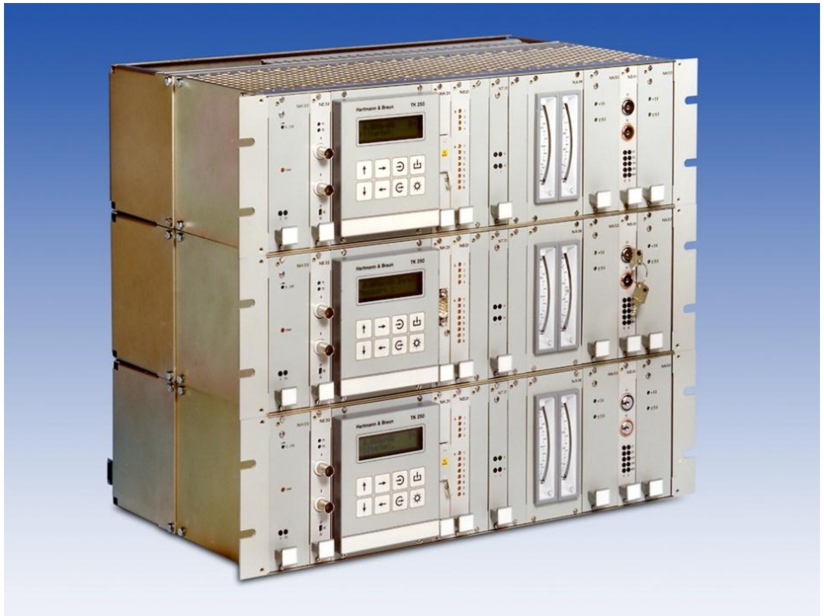
- Achieved through “progressive barrier/firewall”
  - No access for external computer,

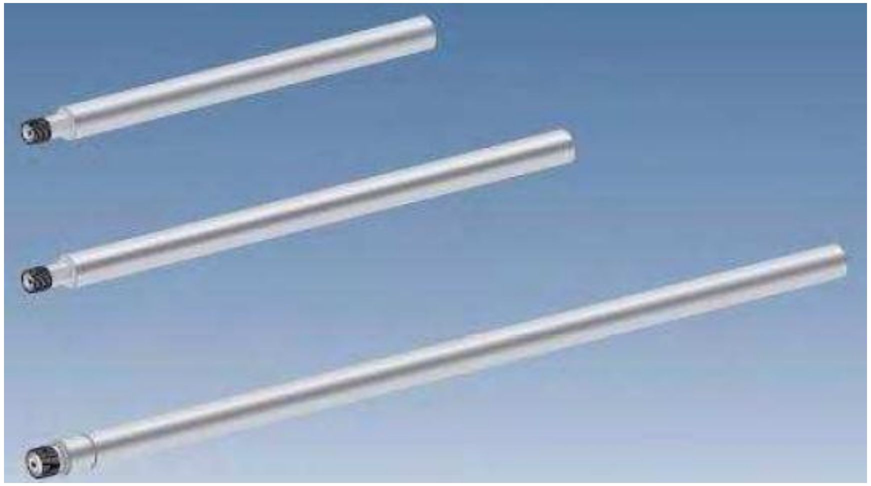
    fully manual access
  - “Read-only” parameters and results
  - Dedicated op-codes only,
    e.g. re-calibration or activation of test
  - Full access by external computer

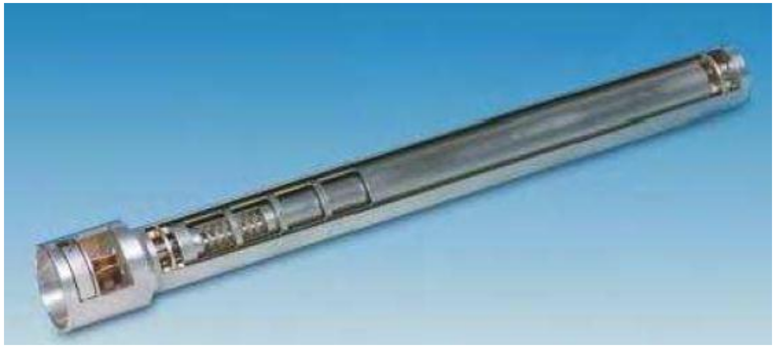
6. proTK^{TM} / TK 250 - NFMS (continued) Channel Types

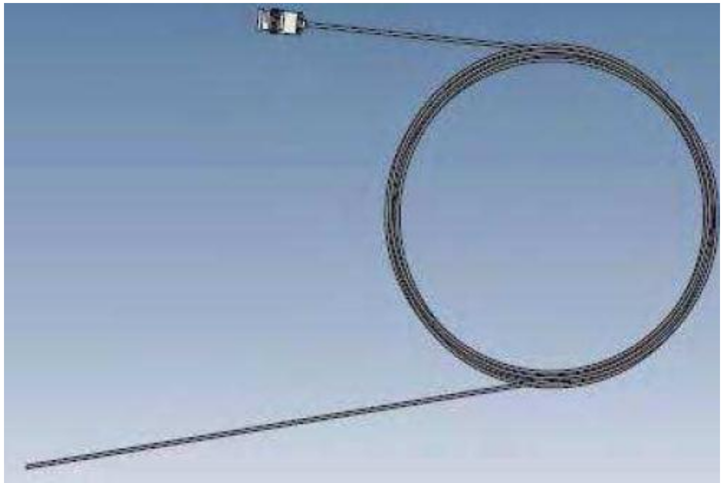
- DAK 250 - Source and Intermediate Range Monitoring
  - with pulse or DC signal processing; reactimeter optional
- DWK 250 - Wide Range Monitoring
  - combined pulse and Campbell processing for in-/out-core fission chambers
- DGK 250 - Power Range Monitoring
  - with 1 or 2 signal paths for neutron ionization chambers
- DLK 250 - Flux Distribution Monitoring
  - for 3 or 6 SPN-detectors with background compensation, calibration and noise reduction
- DSK/DMK 250 – Local/Average Power Range (BWR)
  - for average and flow related flux with stability monitoring

6. proTK$^{\mathrm{TM}}$ / TK 250 - NFMS (continued) Digital Channel & Detectors





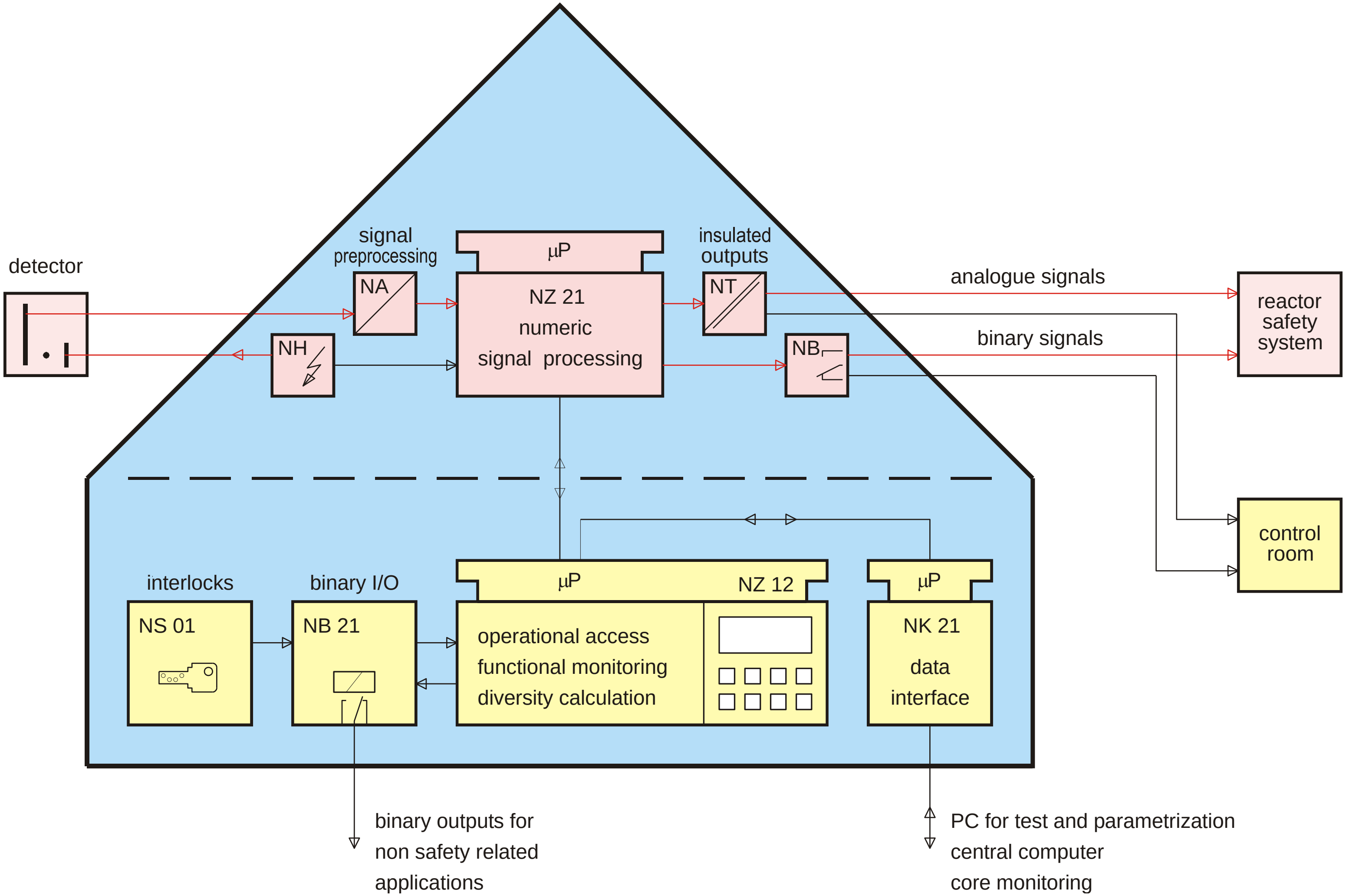




6. proTK™ / TK 250 - NFMS (continued) Features

• Modular system – easy to adapt into an existing plant	**Flexible**
• Signal processing software fixed in EPROM	**Safe**
• Remote test signals, electrical & digital	**Verifiable / Testable**
• Designed and type tested – according to KTA and IEC standards	**Qualified**
• Long operational experience	**Reliable**

6. proTK™ / TK 250 - NFMS (continued)
System Architecture



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Learn more at: **www.mirion.com**

MIRION TECHNOLOGIES

Radiation Monitoring Systems Division

6. proTK^{TM} / TK 250 - NFMS (continued) System Design – Clear & Simple

- **The functions for the safety signal path are concentrated on the independent I/O-micro-processor board NZ 21:**
  - **The software is purely sequential and deterministic**
  - **The software operates cyclic in a fixed time grid, e.g. 10 ms**
  - **Therefore, the response time is predictable**
  - **There is no operating system**
  - **The volume of the software is as small as 3 to 8 kByte**
- **All other functions e.g. operator’s access or self monitoring are allocated on the “main processor board” NZ 12**
- **Re-use of type-tested and proven software modules**
- **The target: zero-fault software**
  - **Designed and developed by well-trained engineers**
  - **Verified by typetest of independent experts (TÜV)**
  - **True proven by long-term operational experience**

6. proTK^{TM} / TK 250 - NFMS (continued) System Design – “Defeating” CCF

- **Measures against CCF of the software**
  - **Additional to the simple and clear design there is:**
    - **No use of interrupts on NZ 21, only 1 timer interrupt on NZ 12**
    - **No use of real time clock or calendar**
    - **NZ 12 has no direct access to NZ 21 and its**
      - ✓ **Program sequence**
      - ✓ **Data or parameter memory**
    - **NZ 21 is hardware-locked by key switch against access to parameters and test-procedures (DGK & DMK 250)**
    - **A variety of self monitoring devices, some of them complementary between NZ 12 and NZ 21**

6. proTK^{TM} / TK 250 - NFMS (continued) System Design – Self Monitoring

- A variety of items is used to detect faults of hardware and software, e.g. monitoring of internal voltages, arithmetics, time schedule, micro-processors, transfer of data, data and program memory. Additional, there are two very efficient tools:

  - NZ 12 performs a “re-calculation” of the results
    - ✓ Using a snapshot of data transferred from NZ 21
    - ✓ Using a different software and arithmetic package (e.g. floating point package instead of fixed point arithmetics)
    - ✓ Comparing the results and generating an alarm if necessary

  - A cycle counter on NZ 21 is interpreted periodically by NZ 12
    - ✓ The differences of two readings are compared with setpoints
    - ✓ NZ 12 & NZ 21 are monitoring their cycle times one another
    - ✓ The response of NZ 12 is additionally monitored by a watch dog

6. proTK^{TM} / TK 250 - NFMS (continued)
System Design – Self-Checks & Tests

- **Different tools make periodical testing efficient but easy:**
  - **Test generators in pre-amps or input-boards of the channel:**
    - ✓ **May be activated remotely without manipulation in the wiring**
    - ✓ **Insert a reference signal to the input of the electronic channel**
  - **The tool “simulation” enables to:**
    - ✓ **Insert arbitrary numbers at defined points of the signal path**
    - ✓ **Generate all desired output values for analog signals or alarms**
  - **Binary outputs (relays) may be activated or deactivated**
  - **All testing tools are locked by key-switch and generate a flag signal**
  - **The basic procedure for periodical testing**
    - ✓ **Is described in the user manual**
    - ✓ **Was checked by TÜV during type test**

6. proTK^{TM} / TK 250 - NFMS (continued)
System Design – Type Testing

- The type test of hardware was performed according to KTA 3505
  - Theoretical and practical tests observed and checked by TÜV
  - Test results transferable to IEEE 323 or IEC 60780
  - Data of operational experience for all boards available
- Software type test also was performed by independent experts:
  - DAK, DGK, DLK 250 and all other channels by TÜV-Nord/Hamburg
  - IEC 880 was applied for DAK, DGK and DLK 250, elements of FMEA
  - Result: the software is qualified for the use in the level of RPS
- Finally an integration test of hardware and software was performed:
  - e.g. functions, characteristics, dynamic response, EMC
  - Some tests also under worst-case conditions

6. proTK^{TM} / TK 250 - NFMS (continued) System Design – Operator Access

- **The access to parameters and testing is locked by 2 key switches**
  - **Without key: parameters may be displayed, but not modified**
  - **DGK 250 additionally has a separated access to re-calibration**
- **A parameter protocol may be generated on a PC via serial interface using purely read-only instructions**
- **The variety of functions and parameters is limited by “configuration” according to customer/project requirements:**
  - **Delete (enable and hide) unused functions**
  - **Establish “fixed parameters”, e.g. scalings or trip thresholds**
  - **Use of modified text tables, e.g. language version**
  - **Configuration is done by Mirion Technologies and checked by TÜV**
  - **Configuration data are stored in EPROM**

6. proTK^{TM} / TK 250 - NFMS (continued) Installations - NPPs

Country	Name/Unit(s)	Type	Year(s)	Installed Channel(s)/Module(s)
CH	Mühleberg	BWR	1994	WRM
CH	Beznau-1/2	PWR	1997…	WRM
DE	Würgassen	BWR	1989…	WRM, LPRM, APRM
DE	Philippsburg-1	BWR	1993/94, 2003…	LPRM/APRM, WRM
DE	Philippsburg-2	PWR	2005/09	SRM, IRM, PRM, N16
DE	Obrigheim	PWR	1995/96	SRM, IRM, PRM, N16
DE	Krümmel	BWR	1997...	WRM, LPRM, APRM
DE	Isar-1	BWR	2000, 2007	WRM, LPRM, APRM
DE	Neckarwesth.-1/2	PWR	2008/2009	SRM, IRM, PRM
B	Doel 3/4, Tihange 2/3	PWR	from 2012	SRM, IRM, PRM
SK	Bohunice	VVER	1997 …	Input boards for WRM
HU	Paks	VVER	1998 …	Input boards for WRM
S	Oskarshamn	BWR	1998 ...	Input boards for WRM and LPRM

Legend: see next page

6. proTK^{TM} / TK 250 - NFMS (continued) Installations - TRTR

Country	Name / Short	Year	Installed Channel(s)
DE	Berlin, Research Reactor / HMI	1999…	SRM, IRM, PRM, N16
DE	Garching, Research R. / FRM-2	2000	WRM
DE	Geesthacht, Research R. / GKSS	2001…	SRM, IRM, PRM
DE	Dresden, Training Reactor / AKR-2	2003…	SRM, IRM
NL	TU-Delft, Research R. / HOR	2010	SRM, IRM, PRM, RMS
US	NIST (Center for Neutr. Res.) / NCNR	2012	SRM
US	MIT Nuclear Reactor Lab. / MITR-II	2012	WRM

Legend

DE	Germany	**SRM**	Source / Start-up Range Monitor	**BWR**	Boiling Water Reactor
CH	Switzerland	**IRM**	Intermediate Range Monitor	**PWR**	Pressurized Water Reactor
B	Belgium	**PRM**	Power Range Monitor	**VVER**	Russian Pressurized Water Reactor
NL	Netherlands	**WRM**	Wide Range Monitor		
US	USA	**LPRM**	Local Power Distribution Monitor		
SK	Slovakia	**APRM**	Average Power Monitor		
HU	Hungary	**N-16**	N-16 Process Monitor		
S	Sweden				

6. proTK^{TM} / TK 250 - NFMS (continued) Summary Operational Experience

• Number of channels in operation	> 280
• Number of reactors	> 20
• Total number of years in operation	> 3,000 years
• Average MTBF of the electronic boards	4,000,000 hours
• Total number of software failures	0

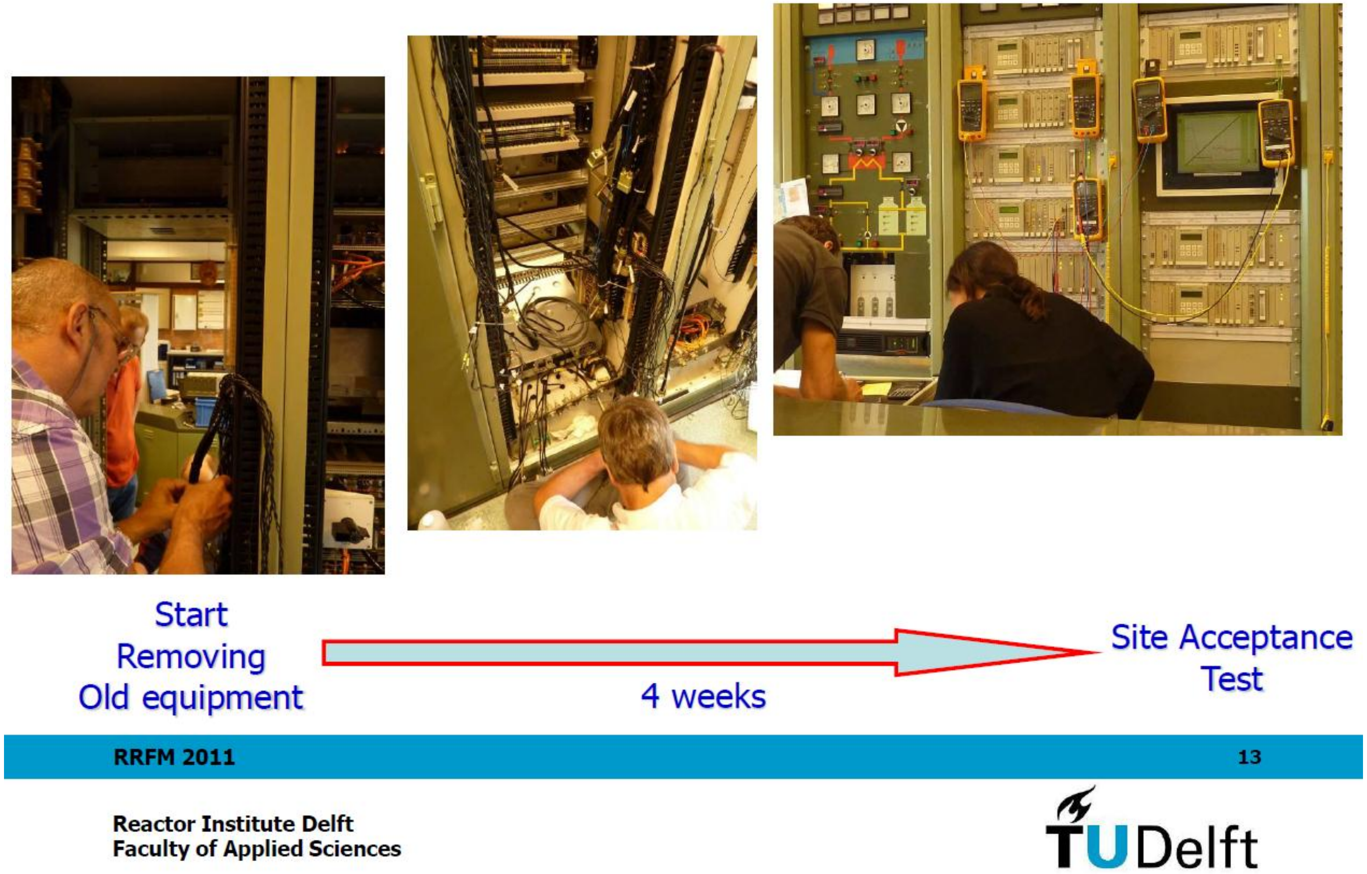
6. proTK^{TM} / TK 250 - NFMS (continued)

Refurbishment Project HOR@TU Delft

Picture from http://tnw.tudelft.nl/

6. proTK^{TM} / TK 250 - NFMS (continued)

Refurbishment Project HOR@TU Delft



Start
Removing
Old equipment

4 weeks

Site Acceptance
Test

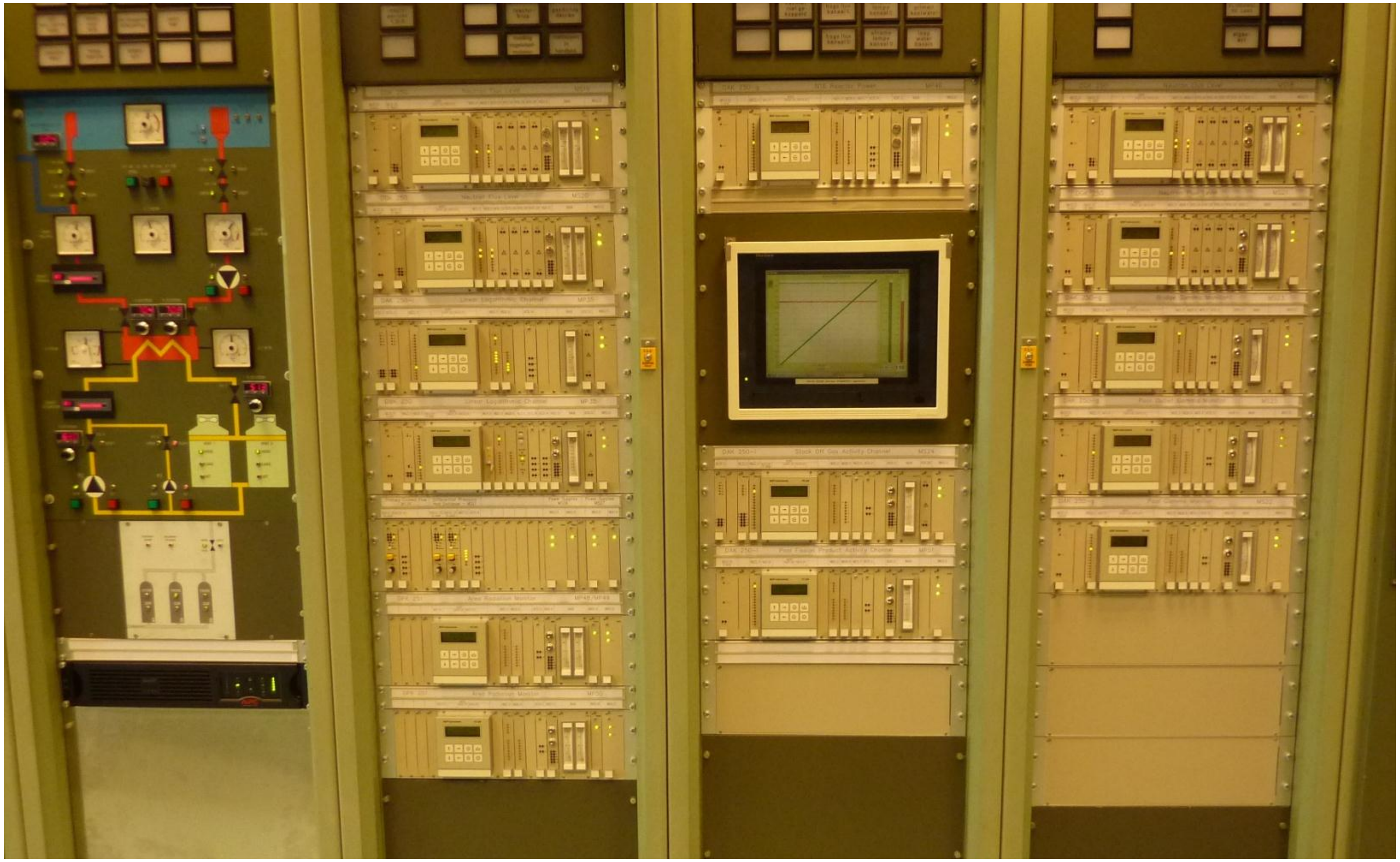
RRFM 2011 13

Reactor Institute Delft
Faculty of Applied Sciences

By courtesy of
C.N.J. Kaaijk, Presentation at RRFM 2011, Rome (Italy)

6. proTK^{TM} / TK 250 - NFMS (continued)

Refurbishment Project HOR@TU Delft



Summary

- Advantages of digital signal processing
  - Increased performance (adaptability, flexibility , functionality)
  - Improved safety, reliability & availability
  - Reduced overall “life cycle” cost
- IT (cyber) security risks can be managed
  - “Progressive” barrier/firewall according to needs
- Digital signal processing channels TK 250
  - Offer all the advantages of a digital signal processing system
  - Proven reliability through more than 3000 operation years, achieved with more than 280 installed channels

Thank you for you attention!

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